Assessing Taiga-tundra Boundary with Multi-Sensor Satellite Data

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INTRODUCTION

Monitoring the dynamics of the circumpolar boreal forest (taiga) and Arctic tundra boundary is important for understanding the causes and consequences of changes observed in these areas.

Forest-tundra zone is naturally fragmented and contains patches of relatively heavy forest cover punctuated by areas of lichen-heath as well as areas of very sparse tree growth.

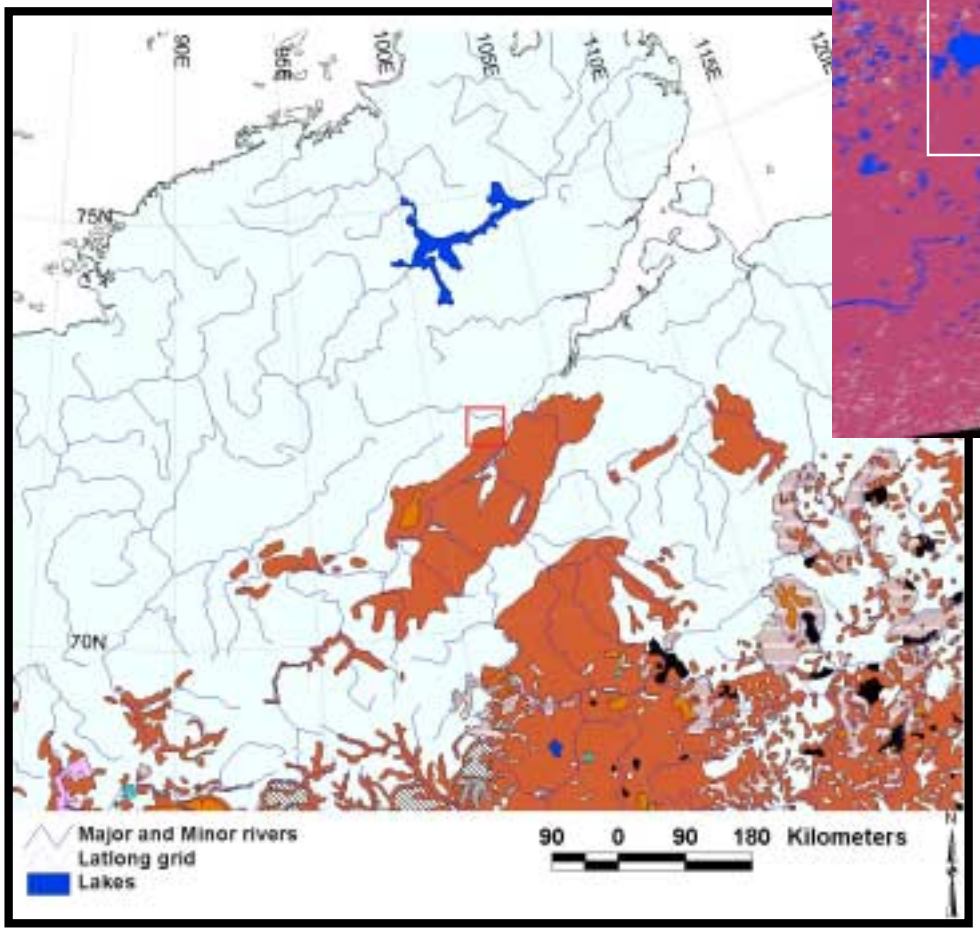
Because of the inaccessibility and large extent of this zone, remote sensing data can play an important role for mapping the characteristics and monitoring the dynamics.

Basic understanding of the capabilities of existing space borne instruments for these purposes is required.

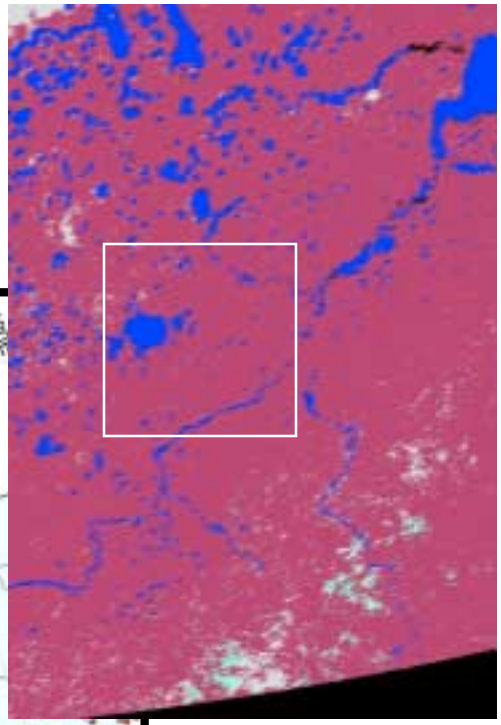
STUDY AREA

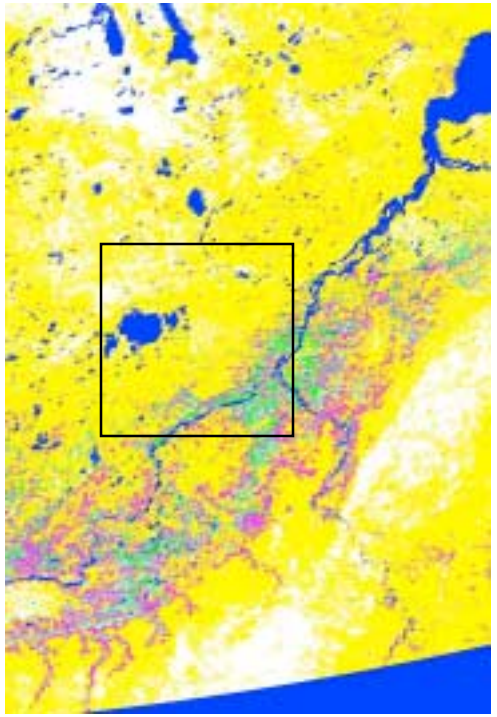
Ary-Mas

(72°28'N 101° 40'E)



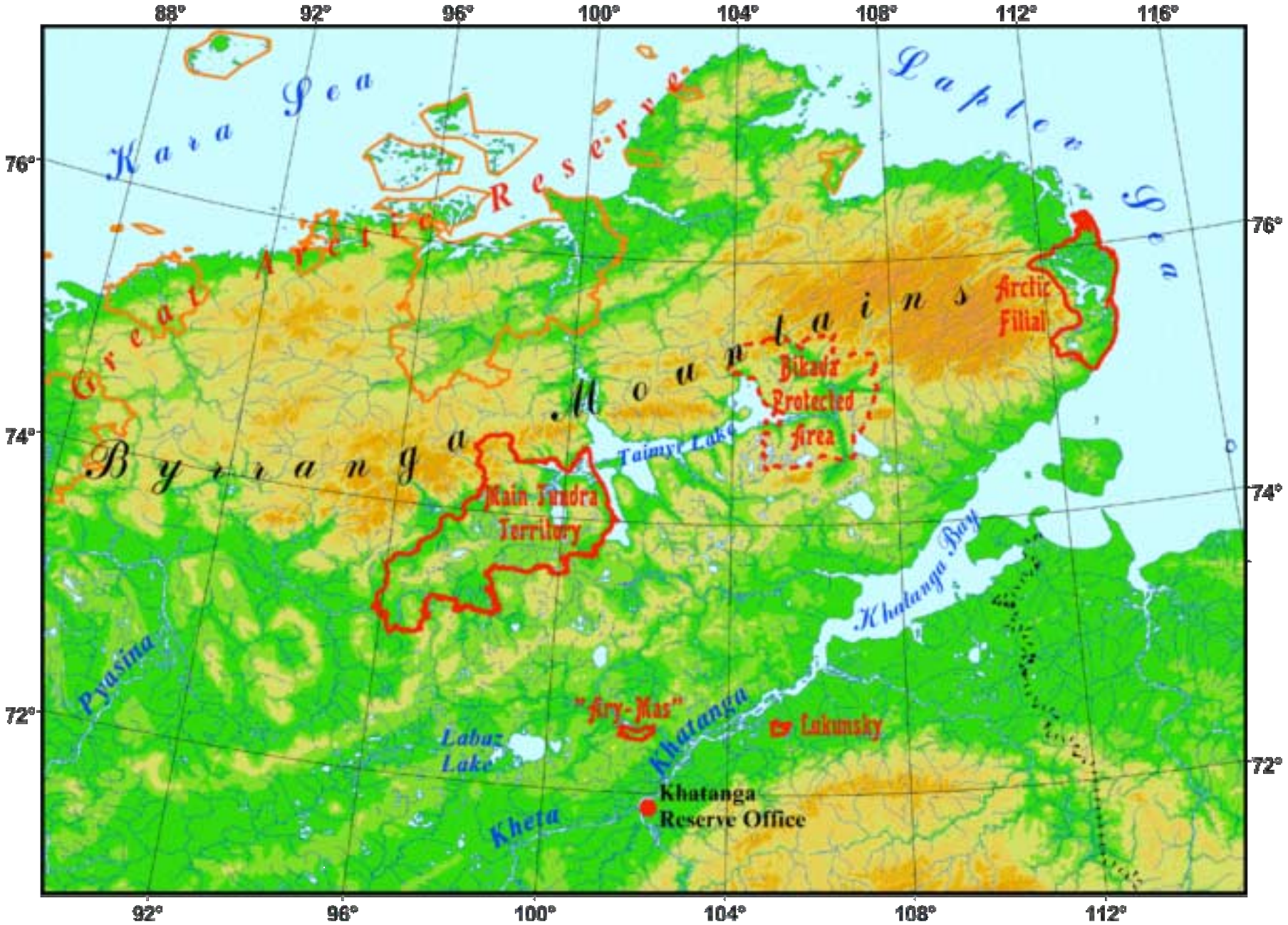
Russian Land Cover map





ABOVE – Left:
MOD12Q1 – Land Cover Type:
Most area is open-shrub (Maroon)
(The green-white area is savanna and bare surface)

ABOVE – Right:
MOD44B – tree coverage
(yellow: 1-5%, Pink: 6-10%, Green: 11-20%, white – no trees)


88°
92°
96°
100°
104°
108°
112°
116°
76°
74°
72°
Kara Sea
Laptev Sea
Great Arctic Reserve
Byrranga Mountains
Arctic Filial
Bikada Protected Area
Taimyr Lake
Main Tundra Territory
Khatanga Bay
Lukunsky
"Ary-Mas"
Labaz Lake
Khatanga
Kheta
Pyasina
Khatanga Reserve Office

PHOTOS OF ARY-MAS FRON SPRING TO FALL

(Author of photos I.Pospelov)

Salix in Ary Mas, springtime

The most typical dense forest at Ary-Mas

It is autumn. Grasses and shrubs _____ _ _____ become yellow earlier than larch trees.

"Taimyrsky" Reserve

The first sunset on Ary-Mas - 5 of August.

OBJECTIVES

- Examine the capabilities of several remote sensing data (Landsat-7 ETM+, RADARSAT, MISR, and MODIS) for identifying the existing taigat-tundra ecotone

- Study the changes of the taiga-tundra zone from 1973 to 2002

Data

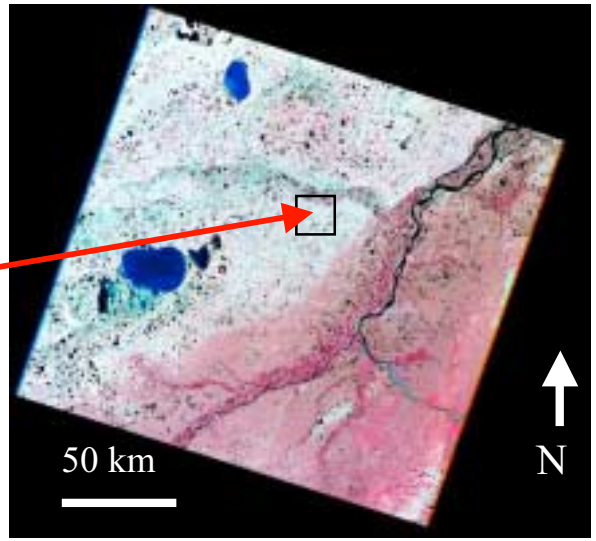
Remote Sensing Data:

Data	Acquisition Date	Characteristics
Landsat-7 ETM+	**07-17-2002**	1-7 Bands
Landsat-1 MSS	07-26-1973	4-7 Bands
RADARSAT ST4	08-15-2001	36.56^{o}
RADARSAT ST5	08-08-2001	39.22^{o}
RADARSAT ST6	08-11-2001	44.14^{o}
IKONOS	**07-17-2002**	B,G,R.NIR, pan
MISR	**07-17-2002**	MISR reflectance in B,G,R,NIR bands, 9 look angles: DF=70.5^{o}, CF=60.0^{o}, BF=45.6^{o}, AF=26.1^{o}, AN=0^{o}, AA=26.1^{o}, BA=45.6^{o}, CA=60.0^{o}, DA=70.5^{o}
MOD13A1	05-25-2001 to 10-16-2001	MODIS 500m 16-day composite NDVI, Red and MIR reflectance products.

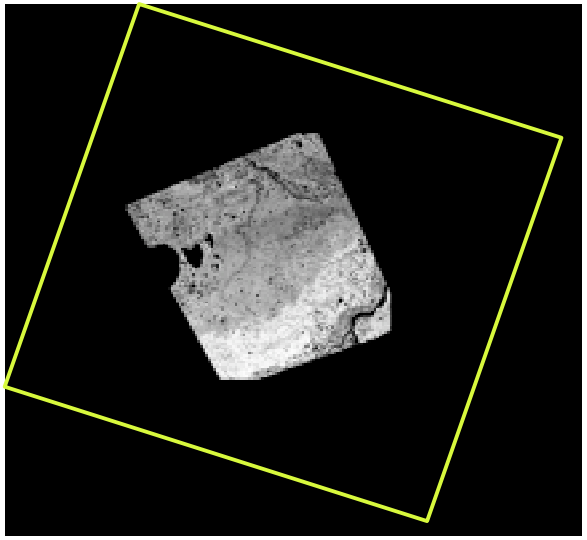
Field observation and Land cover map:

An early land cover map and field samplings 1n 1969-71, 1989-91 and 2000

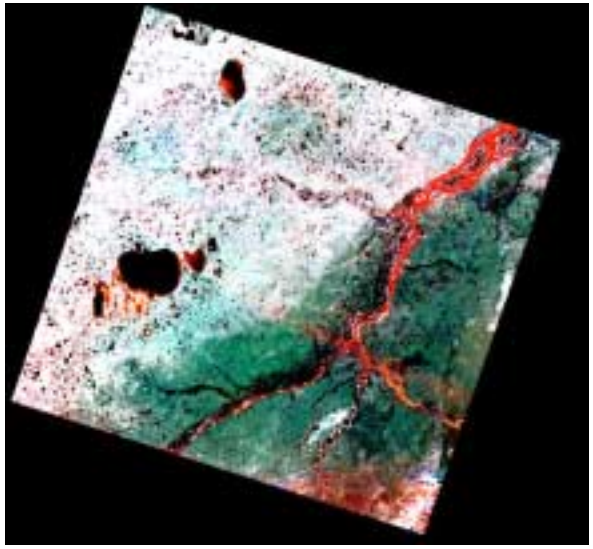
IKONOS
IMAGE



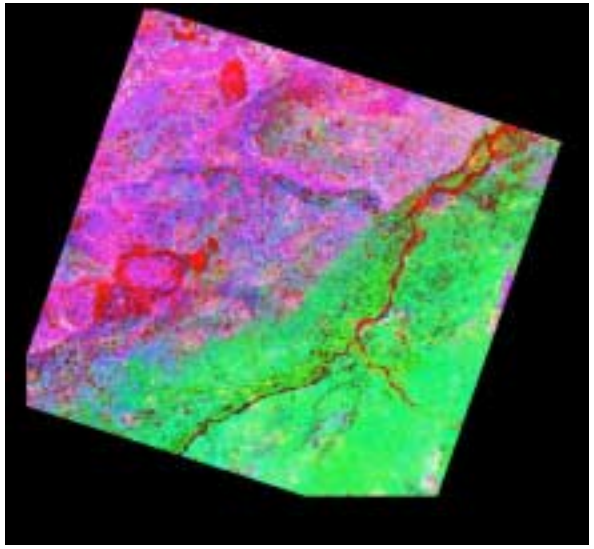
Landsat-7 ETM+ B4,3,2



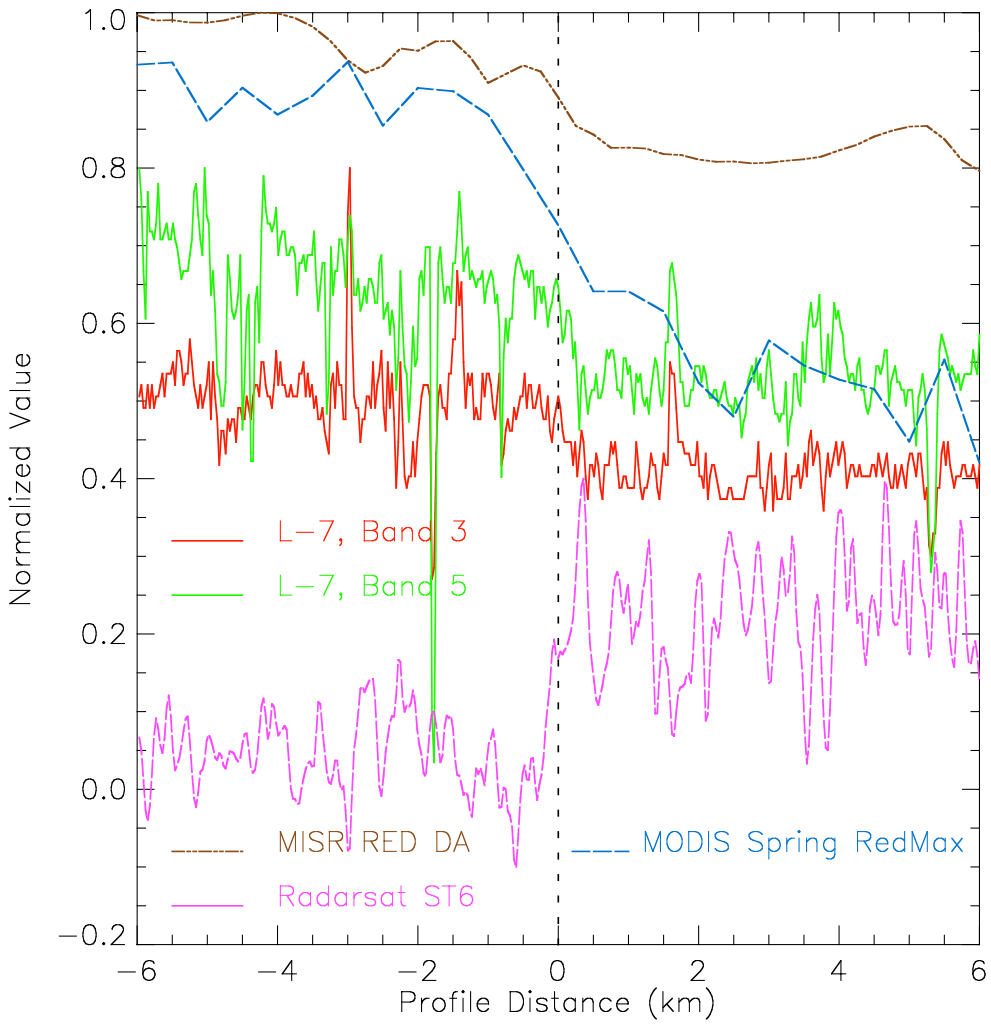
RADARSAT ST6



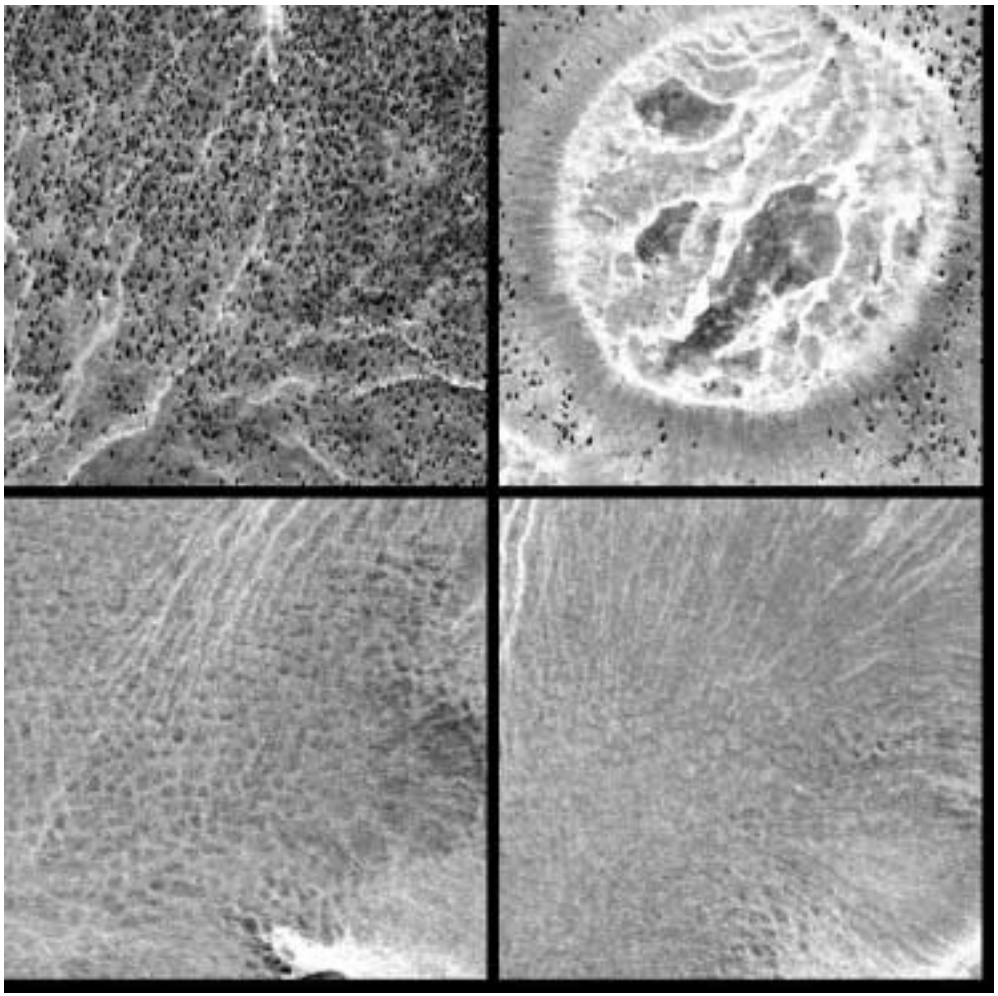
MISR RED DF, AN and DA



MODIS RED, NDVI, MIR



Signature profiles of ETM+, RADARSAT, MISR and MODIS data across a tundra-taiga transition boundary



IKONOS 1m pan images of typical targets:
Taiga, Bog, and Tundra

METHOD

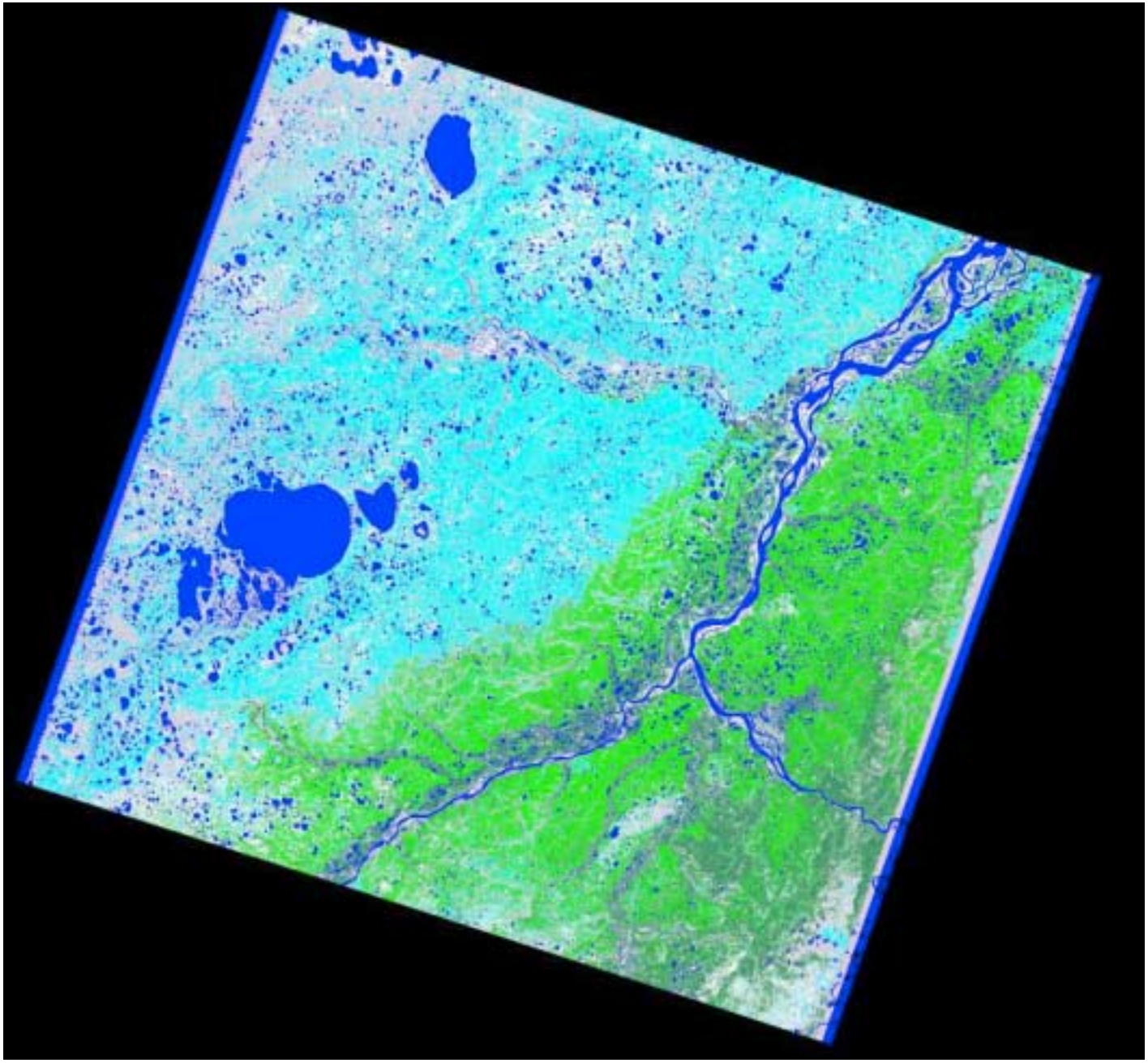
- Georefrencing and co-registration
- Classification of L-7 ETM+ images
- Mask of taiga and tundra areas
- Linear spectral unmixing
- Taiga abudance analysis
- Change analysis

Georefencing

- L-7 ETM+ image at Siberia LCC projection (accuracy ~ 50m)
- Re-project and subset MODIS data to LCC (accuracy ~ 150m)
- Re-project, subset and re-sample MISR Red band data to LCC projection (accuracy 143m – 372m)
- Image-to-image co-registration of RADARSAT images to L-7 ETM+ image (error < 60m)

ETM+ Classification

- IKONOS image and Land cover map as training and testing data
- MLC classification (10 classes)
- Generating tundra and taiga mask image and locate end-members (pure tundra and dense taiga)

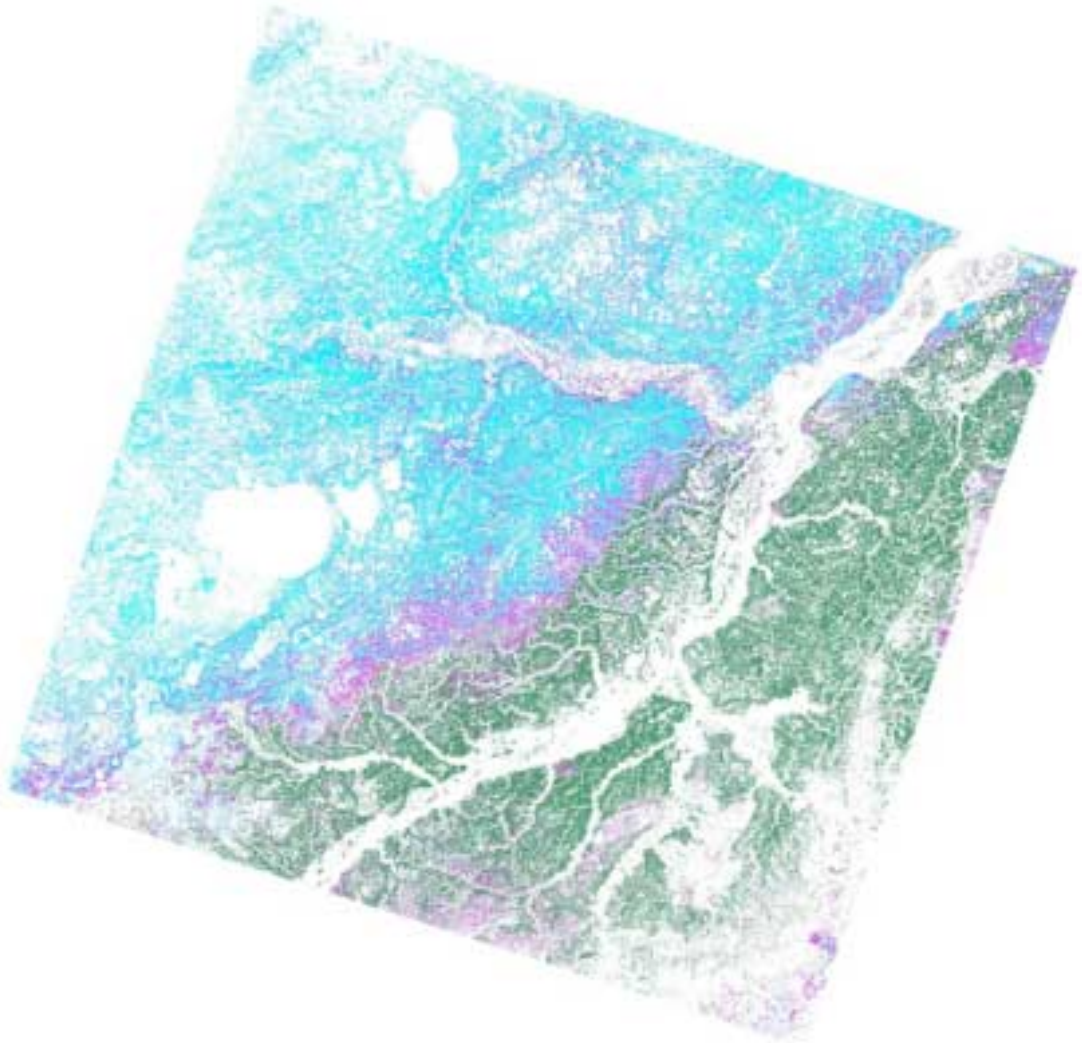


Classification
Of L-7 images

Major classes:
Green – Taiga
Cyan – Tundra
Blue – Water

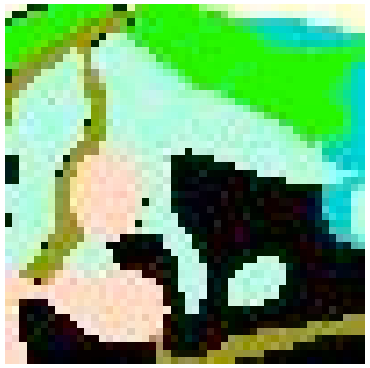
Linear Spectral Unmixing

- End-mambers identified on L-7 ETM+ image
- Other data were re-sampled into 30m pixel
- Linear Unmixing of pixels belong to ‘taiga’ or ‘tundra’ only

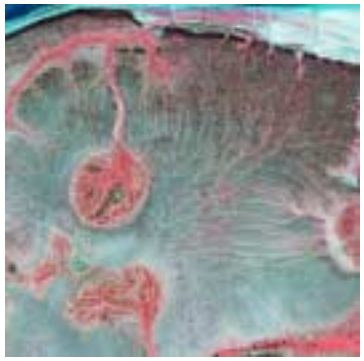


Results of Linear Spectral Unmixing of ETM+ data: Cyan – Tundra,
Sea Green – Taiga (>50% taiga), Magenta – Tundra-taiga transition (25-50%)

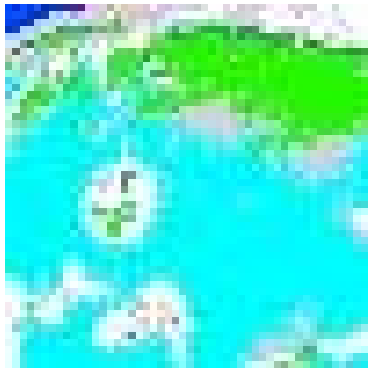
Validation of ETM+ classification and linear unmixing results



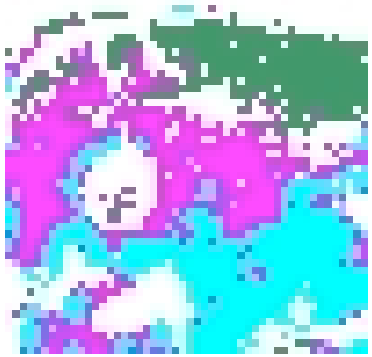
Land Cover Map
Green-taiga, cyan-tundra
Pink - bog



IKONOS



Classification
Green-taiga, cyan-tundra
white - masked



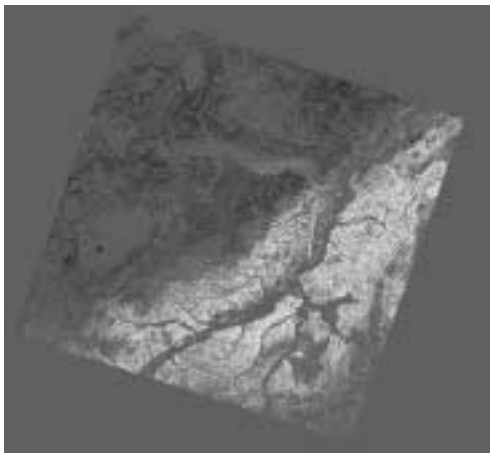
Linear Unmixing
Dark green-taiga, cyan-tundra
white - masked

Test results of Landsat ETM+ classification

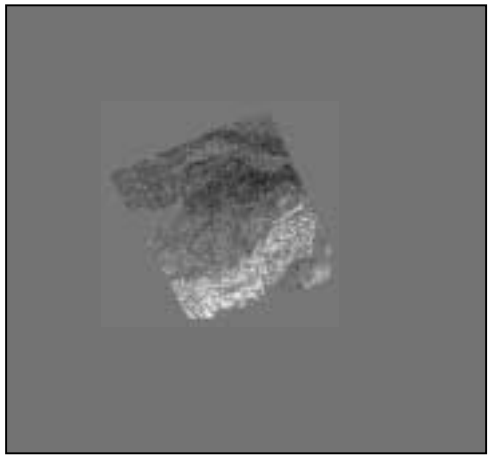
Test Area	Larch	Tundra	Bog	Sand bar	Comments
Larch (higher CC)	36				Accuracy 100%, Crown closure (CC) >0.5
Larch (low CC)	63				Accuracy 100% 0.1≤CC≤0.5
Larch (very sparse)	4	32			Crown closure (CC) less than 0.1, similar to tundra
Tundra	3	42	7		Accuracy 81%
Bog	2	25	102		Accuracy 80%, confused with tundra
Sand bar				41	Accuracy 100%

Taiga Abandance from Linear spectral Unmixing

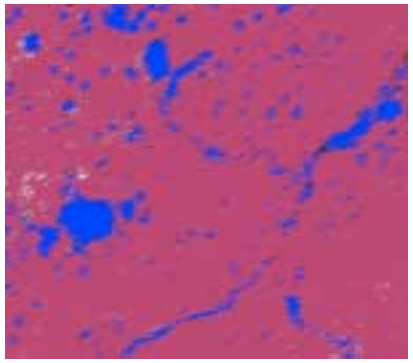
(Dark – bright: 0 – 100%)



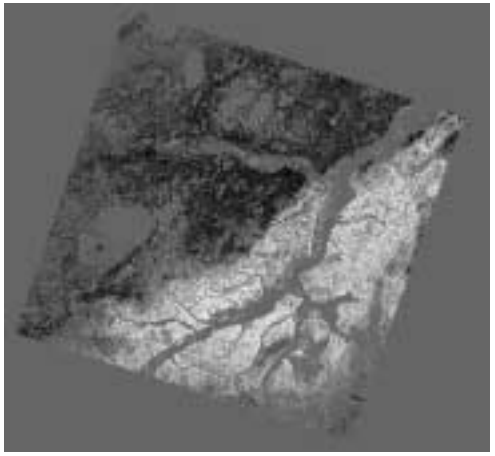
L-7 ETM+



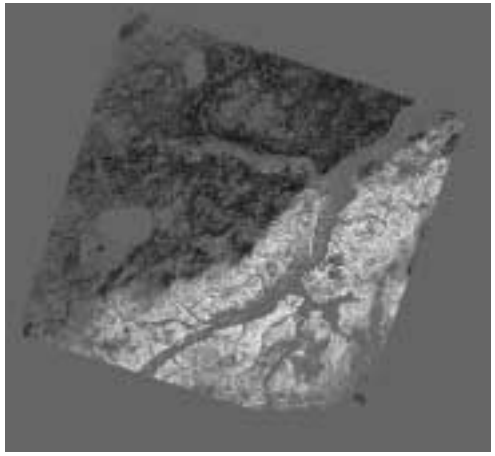
RADARSAT ST4-6



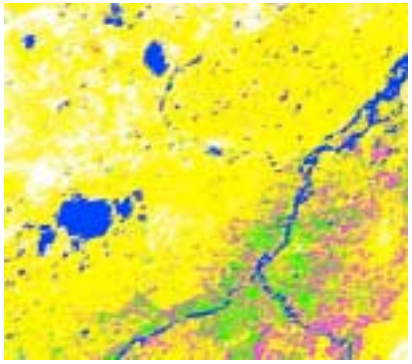
MOD12Q1 – Land Cover Type



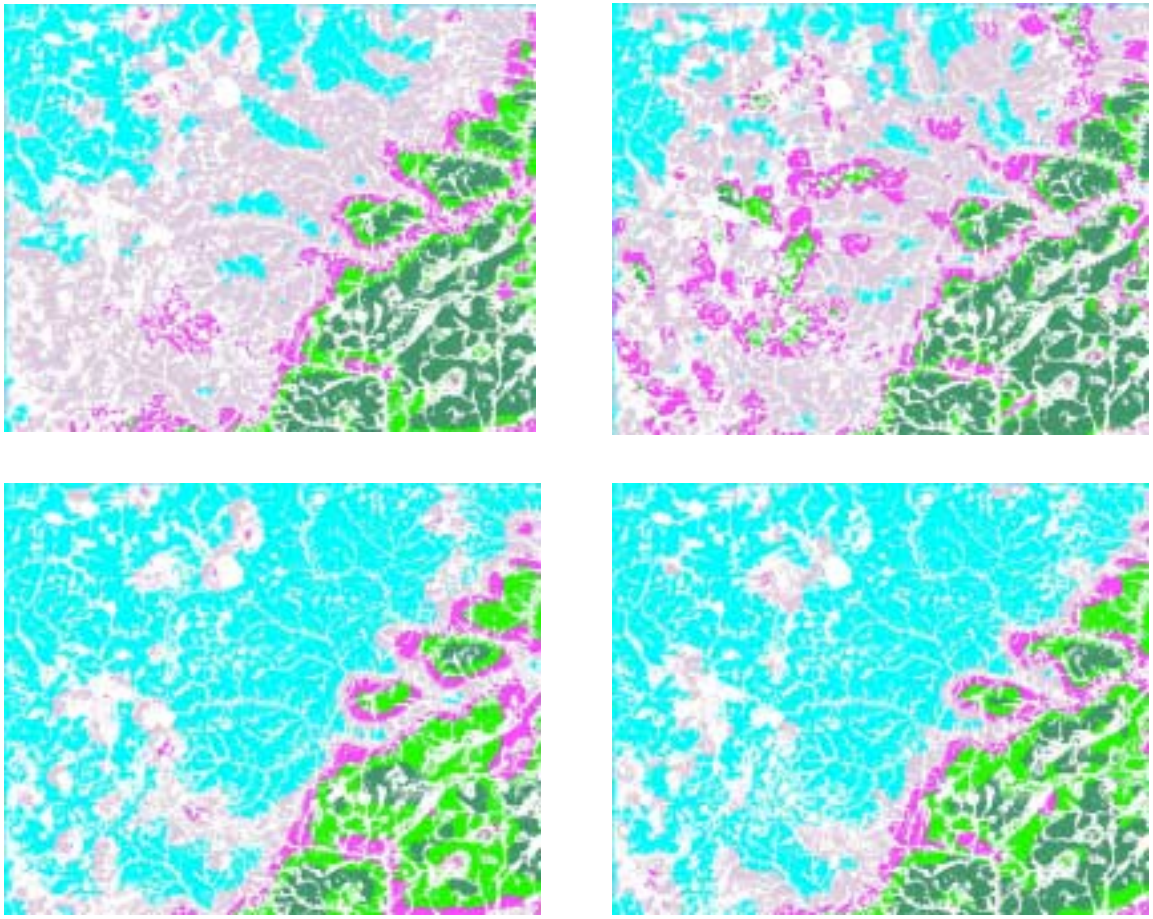
MISR



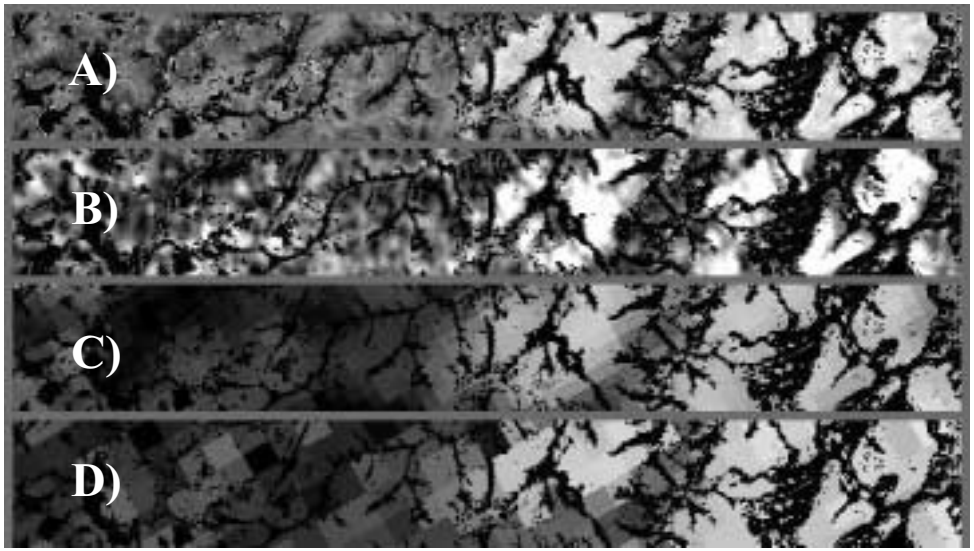
MODIS

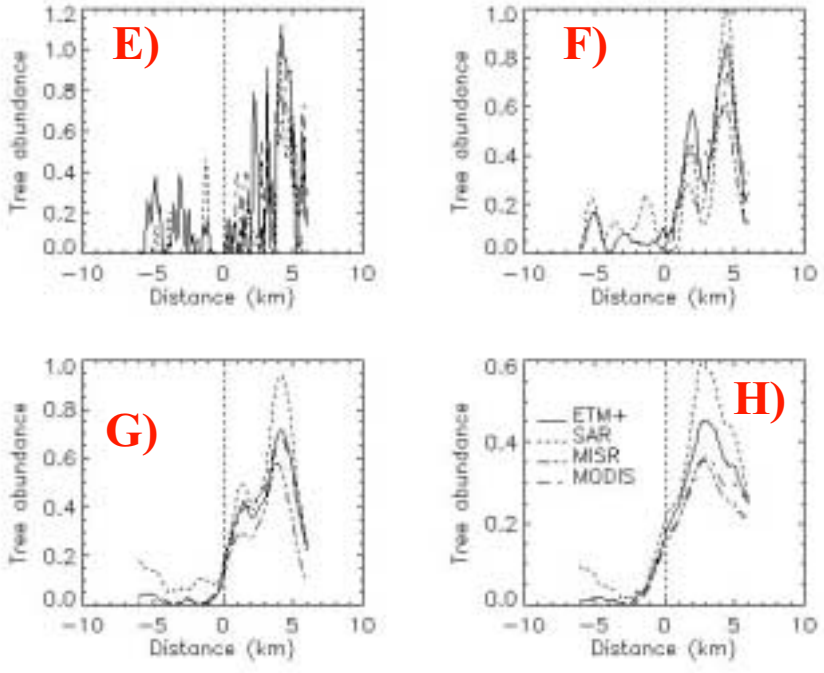


MOD44B – tree coverage



Comparisons of mapped current tundra-taiga transition zone from a) Landsat-7 ETM+, b) RADARSAT multi-beam data, c) MISR red band, and d) MODIS temporal NDVI, red and MIR reflectance. Taiga abundance was calculated using a 1km moving window and color density sliced: cyan - <= 0.0, thistle – 0-0.25, Magenta – 0.25-0.5, light green – 0.5-0.75, and dark green - > 0.75





Images A-D show taiga abundances calculated for a transect crossing the tundra-taiga transition from ETM+, RADASAT, MISR and MODIS data, respectively. Taiga abundances are plotted for each data type using various window sizes:
E) – using a 90m moving window, F) – 510m window, G) – 990m window, and H) – 2010m window. The vertical lines in images (A-D) correspond to the dashed vertical line in graphs.

Results of MODIS taiga abundance classification relative to Landsat.

	Class				
Classified as	Tundra	0-0.25	0.25-0.5	0.5-0.75	Taiga
Tundra	**96.5**	*82.1*	*21.4*	1.1	0.0
0-0.25	3.47	**17.2**	*35.1*	5.1	0.5
0.25-0.5	0.0	0.7	**35.7**	*26.1*	2.1
0.5-0.75	0.0	0.0	7.7	**54.8**	*37.0*
Taiga	0.0	0.0	0.1	12.9	**60.4**
Unclassified	0.0	0.0	0.0	0.0	0.0

Results of MISR taiga abundance classification relative to Landsat.

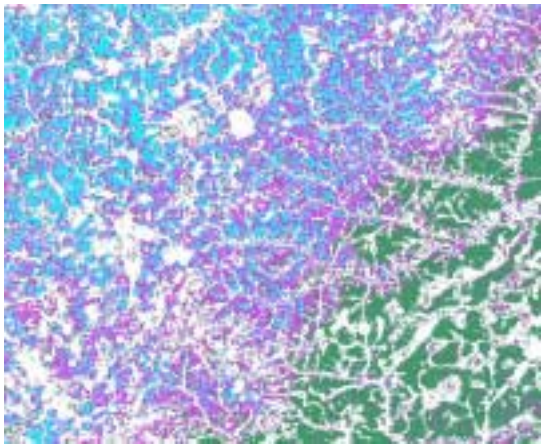
	Class				
Classified as	Tundra	0-0.25	0.25-0.5	0.5-0.75	Taiga
Tundra	**96.6**	*81.9*	9.5	0.0	0.0
0-0.25	3.4	**17.5**	*52.7*	8.1	0.0
0.25-0.5	0.0	0.6	**35.6**	*44.3*	7.0
0.5-0.75	0.0	0.0	2.3	**45.8**	*62.5*
Taiga	0.0	0.0	0.0	1.8	**30.5**
Unclassified	0.0	0.0	0.0	0.0	0.0

Results of RADARSAT taiga abundance classification relative to Landsat.

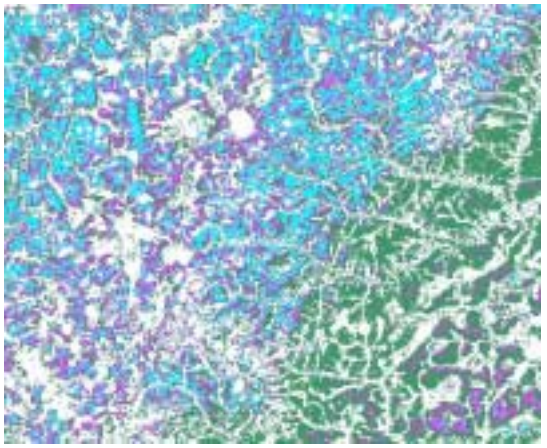
results

	Class				
Classified as	Tundra	0-0.25	0.25-0.5	0.5-0.75	Taiga
Tundra	**42.7**	7.8	1.2	0.0	0.0
0-0.25	*53.0*	**67.6**	*39.8*	0.9	0.0
0.25-0.5	0.6	*21.1*	**44.7**	*23.5*	0.5
0.5-0.75	0.0	3.1	*13.1*	**37.1**	6.2
Taiga	0.0	0.4	1.2	*38.4*	**93.32**
Unclassified	3.7	0.0	0.0	0.0	0.0

From MSS (1973)



From ETM+ (2002)



Cyan – tundra, magenta - <50% taiga, sea green - >50% taiga

Increase of taiga abundance: Yellow – 0-25%, magenta – 25-50%, green - > 50%

CONCLUDING REMARKS

This study has shown that data from Landsat7 ETM+, MISR red band multi-angle data, MODIS time series data, and RADARSAT large-incidence angle images are all sensitive to the surface and vegetation structure change across the tundra-taiga transition zone in our study area. The location of the transition zone from images with very different spatial resolutions was consistent. This implicates that global coverage data available from RADARSAT may be used to analyze where high resolution is required and cloud cover or low illumination precludes the use of Landsat-like data. Current Landsat-7 coverage problems caused by the scan line corrector malfunction make this option especially useful.

For MISR the utility may be limited by frequent cloud cover and the infrequent coverage of MISR. The results suggest that MODIS may be an appropriate tool for longer term monitoring of the ecotone when Landsat data or other high or moderate resolution data is available for training purposes. The 500m data sets used in this study provided useful information, but more work is needed. Further studies will reveal the effectiveness of 250m two channel MODIS data sets. Our future studies will include mapping and characterization of other parts of this transition zone from these remotely sensed data.

ACKNOWLEDGMENTS

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